DRA / HQ

NASW-3950

(NASA-CR-175852) COMETARY ATMOSPHERES: MODELING THE SPATIAL DISTRIBUTION OF OBSERVED NEUTRAL RADICALS Interim Report, Sep. - Nov. 1984 (Atmospheric and Environmental Research) 14 p HC A02/MF A01 CSCL 03B

N85-27781

Unclas
G3/90 15072

# Cometary Atmospheres:
# Modeling the Spatial Distribution of Observed Neutral Radicals

Michael R. Combi

Atmospheric and Environmental Research, Inc.
840 Memorial Drive
Cambridge, MA 02139

January 1985

Interim Report for the Period
September 1, 1984 to November 30, 1984

Prepared for
NASA Headquarters

TECHNICAL REPORT STANDARD TITLE PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| 4. Title and Subtitle<br>Cometary Atmospheres: Modeling the Spatial Distribution of Observed Neutral Radicals | | 5. Report Date<br>January 1985 |
| | | 6. Performing Organization Code |
| 7. Author(s)<br>Michael R. Combi | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>Atmospheric and Environmental Research, Inc.<br>840 Memorial Drive<br>Cambridge, MA 02139 | | 10. Work Unit No. |
| | | 11. Contract or Grant No.<br>NASW-3950 |
| 12. Sponsoring Agency Name and Address<br>NASA Headquarters<br>Headquarters Contract Division<br>Washington, DC 20546 | | 13. Type of Report and Period Covered<br>Interim Report<br>September–November 1984 |
| | | 14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract

The dependencies on heliocentric velocity for the solar photodissociation lifetime and the solar fluorescence rate of the OH radical have been incorporated into the Monte Carlo particle trajectory model for cometary radicals. For the case of CN we have begun a study on the effects of using several different adopted models on the calculation of production rates from filter photometry. Progress in these areas is discussed herein. A comparison of two different sets of scale length data for cometary $C_2$ and CN is also presented.

| 17. Key Words (Selected by Author(s)) | 18. Distribution Statement |
|---|---|
| comets | |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
|---|---|---|---|
| Unclassified | Unclassified | 13 | |

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

## I. Program of Research for the Second Quarter

During this past quarter: (1) the heliocentric velocity dependencies of the OH photodissociation lifetime and the (0-0) band fluorescence rate have been incorporated into the cometary radical model, (2) preliminary evaluation of the effects of radiation pressure and the heliocentric distance dependent parent velocity of CN production rates deduced from photometry has been performed, and (3) study of radical scale length data has been continued.

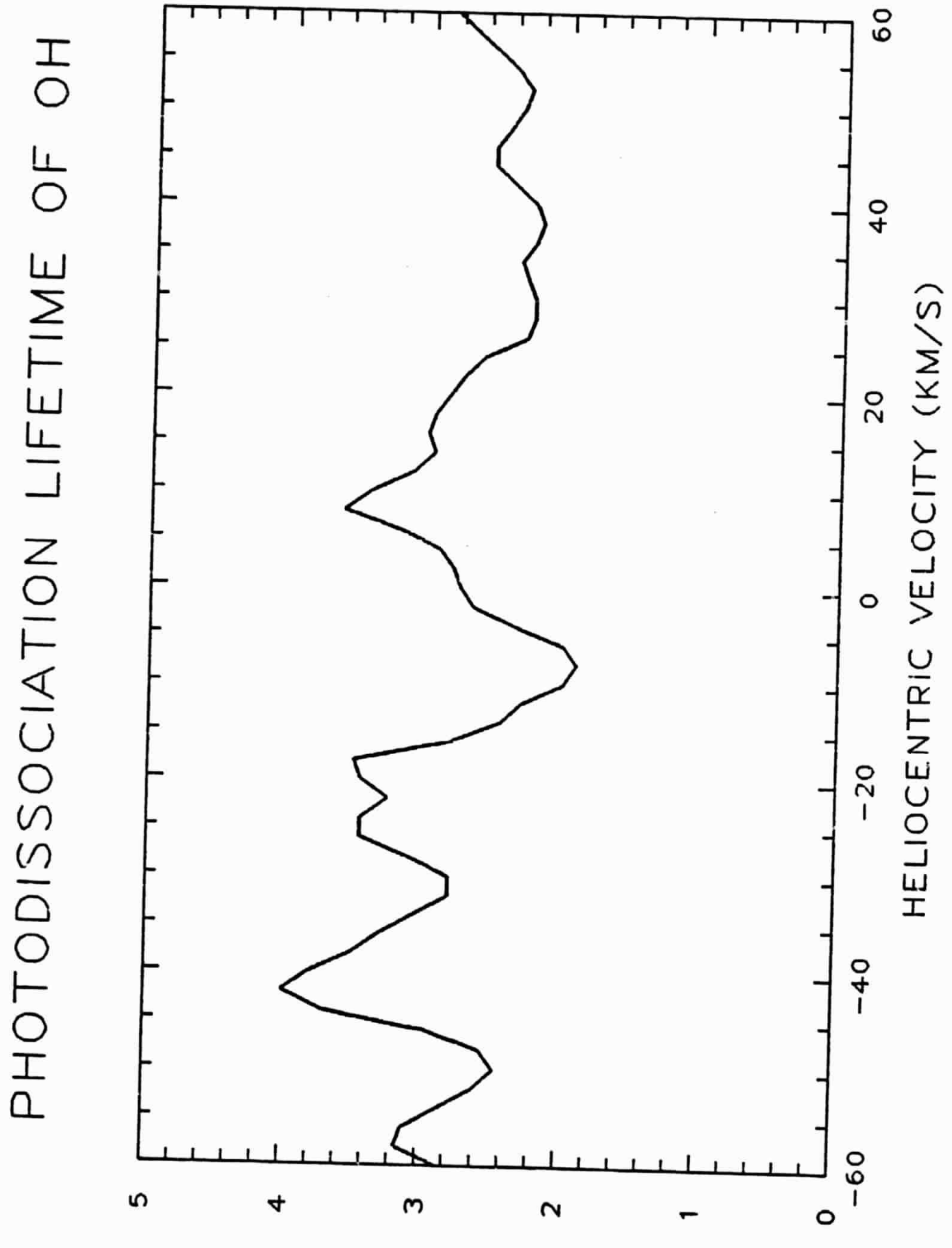
### 1. OH Photochemistry

Schleicher and A'Hearn (1982, 1984) have calculated the dependencies of both the OH photodissociation lifetime and the OH solar fluorescence rate on heliocentric velocity. At a distance of 1 AU from the sun, the OH lifetime can vary from $\lesssim 2 \times 10^5$ s to $\sim 4 \times 10^5$ s depending on the heliocentric velocity. The (0-0) band fluorescence rate varies by more than a factor of 6 for different heliocentric velocities. Figures 1 and 2 show these dependencies which have been incorporated in to the cometary radical particle-trajectory model.

### 2. CN Production Rate

The cometary radical model, which was updated last quarter to include the heliocentric distance dependent parent molecule velocity, $v = 0.58\ r_H^{-1/2}$ (Delsemme 1982), has been applied to recalculate the production rates of CN in Comet West (A'Hearn et al. 1977, A'Hearn and Cowan 1980). A'Hearn et al. (1977) had originally used an $r_H^{+1}$ law for a Haser model parent scale length for CN and found that the production rate for CN varied with heliocentric distance as $r_H^{-2.8}$. Combi and Delsemme (1980b) then measured CN parent scale lengths in Comets Bennett and West and found a dependence of $r_H^{1.8\pm.1}$ which they concluded was reasonably consistent with an $r_H^2$ law. Both they and A'Hearn and Cowan (1980) then adopted the $r_H^2$ law and found a CN production rate varying approcimately as $r_H^{-n}$ where $n \approx 1.6\pm0.3$.

For this study, the CN production rates have been calculated using three different model descriptions and compared with the Haser model parameters A'Hearn and Cowan have adopted. The results of these four cases are shown in Table 1. The first case is a Haser model, using the Average Random Walk Model


PHOTODISSOCIATION LIFETIME OF OH
OH LIFETIME (10**5 S)
HELIOCENTRIC VELOCITY (KM/S)
0
1
2
3
4
5
-60
-40
-20
0
20
40
60

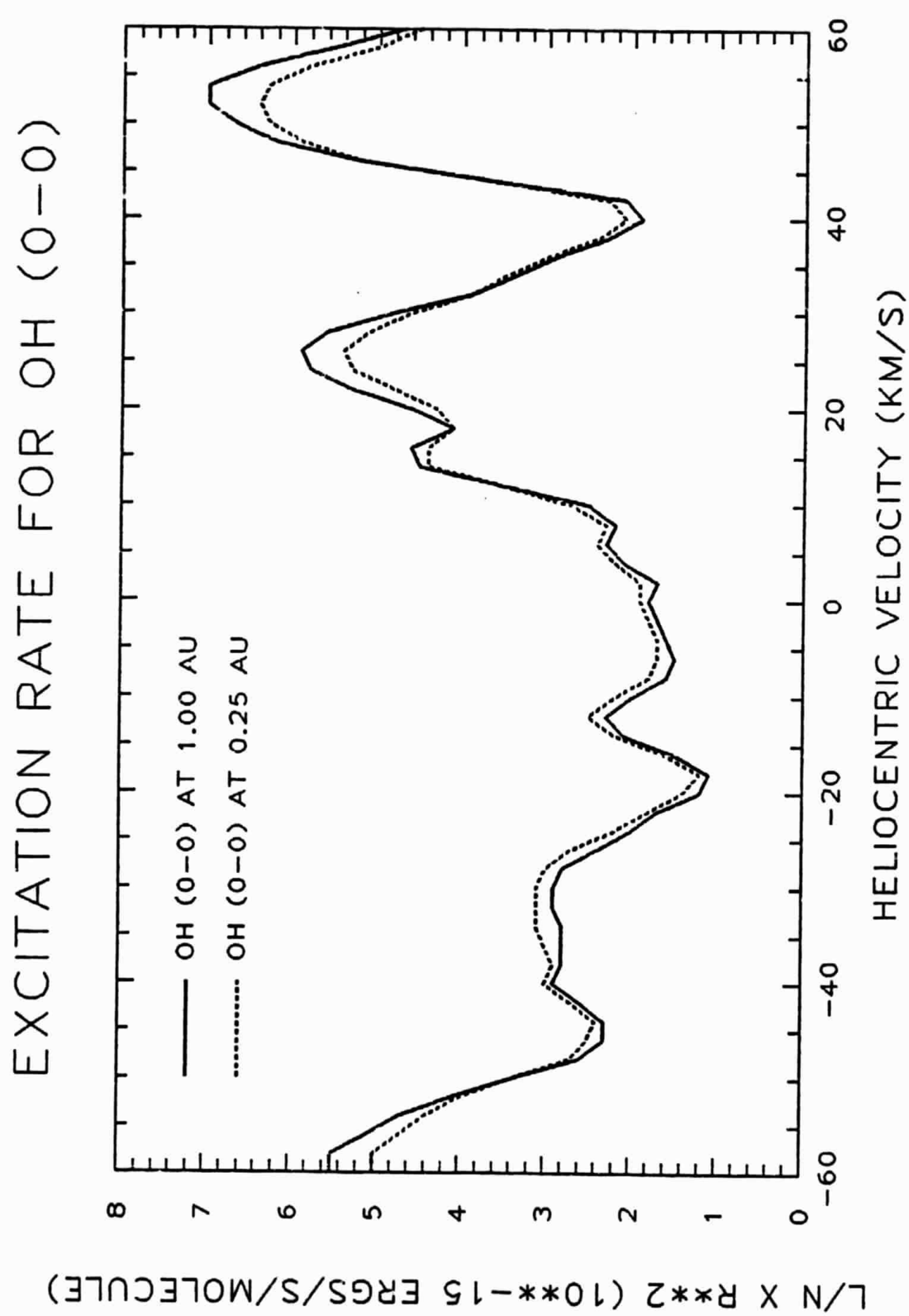

EXCITATION RATE FOR OH (0—0)
OH (0—0) AT 1.00 AU
OH (0—0) AT 0.25 AU
HELIOCENTRIC VELOCITY (KM/S)
L/N X R**2 (10**-15 ERGS/S/MOLECULE)
-60
-40
-20
0
20
40
60
0
1
2
3
4
5
6
7
8

Table 1

CN Production in Comet West

| | Model | $Q_1$ ($s^{-1}$)[a] | n[b] |
|---|---|---|---|
| | A'Hearn and Cowan Haser Model | $1.1 \times 10^{27}$ | -1.61 |
| 1) | Average Random Walk Model | $1.4 \times 10^{27}$ | -2.00 |
| 2) | Monte Carlo Particle Trajectory Model (no radiation pressure) | $1.2 \times 10^{27}$ | -1.92 |
| 3) | Monte Carlo Particle Trajectory Model (with radiation pressure) | $1.3 \times 10^{27}$ | -1.87 |

(a) Production Rate at 1 AU

(b) Exponent in power law $Q = Q_1 \, r_H{}^n$

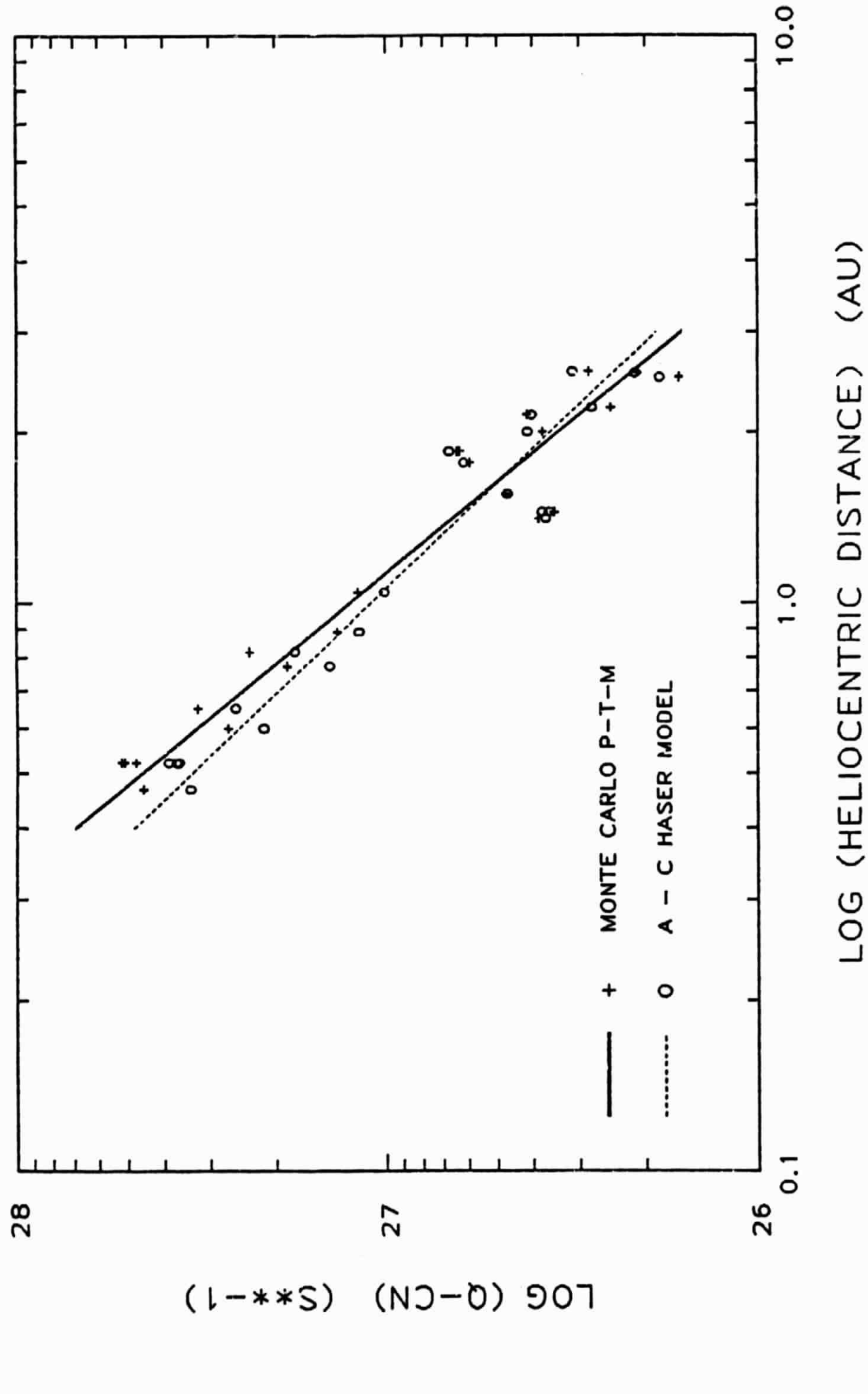
(Combi and Delsemme 1980a) corrections to the scale lengths. Here the $r_H$ variation in parent velocity and the isotropic ejection of the daughter radicals is taken into account in an approximate way. The second case is a Monte Carlo Particle Trajectory Model (MCPTM) which explicitly calculates the effects included in the first case. And the third case is a MCPTM which also includes radiation pressure (Combi 1980). In all cases the heliocentric velocity dependence of the CN(0-0) band excitation (Tatum and Gillespie 1977) is included.

The largest effect is that of the variation of the parent velocity which steepens the slope of the resulting production law and is present in all three cases. The explicit inclusion of isotropic ejection (case 2) and radiation pressure (case 3) each flatten the slope somewhat but are nonetheless important. A comparison of the original Haser model calculations and the full MCPTM (Case 3) for the CN production in Comet West is shown in Figure 3.

## 3. $C_2$ and CN Scale Lengths

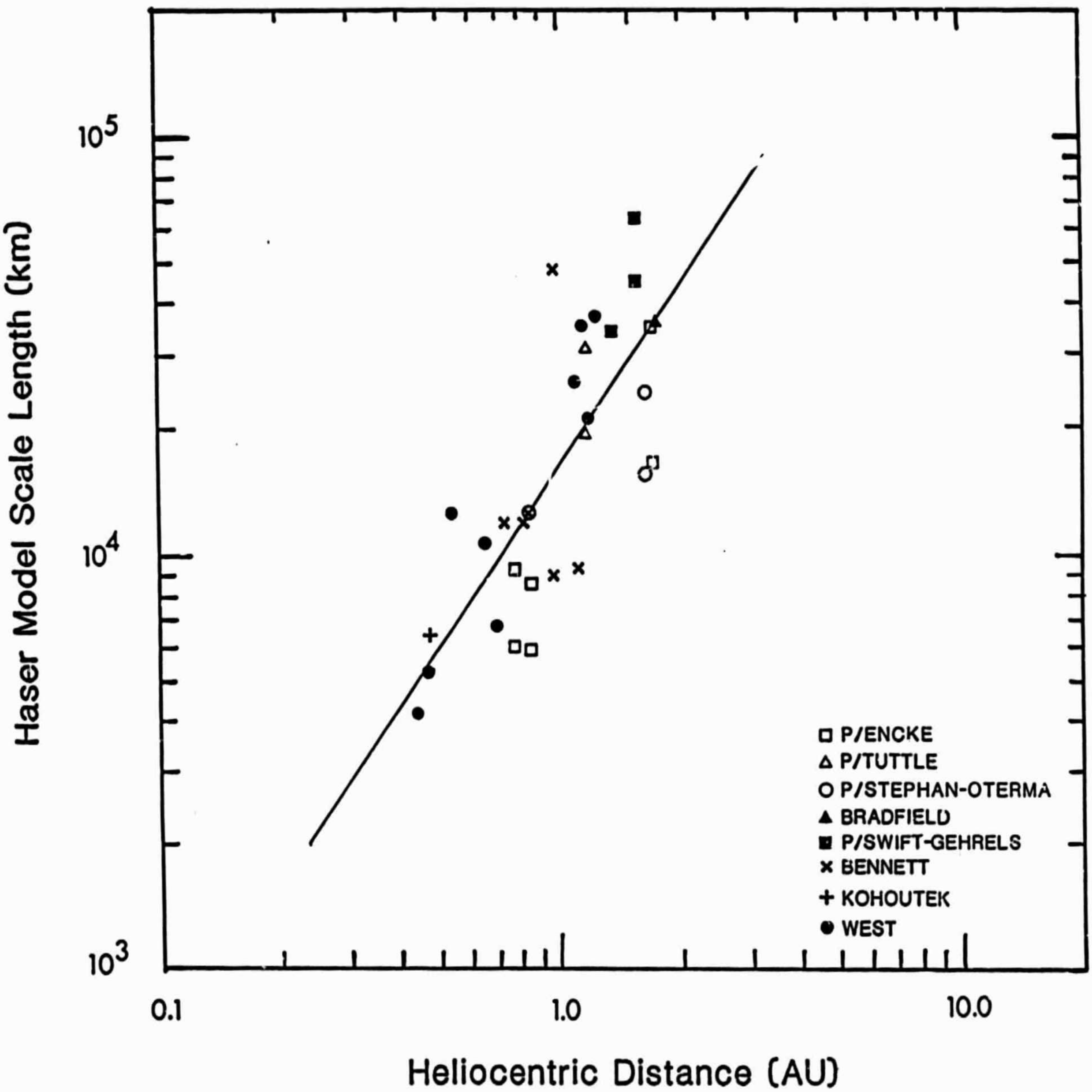
Although Haser model scale lengths cannot be used to give direct physical quantities (lifetimes), they can be useful tools to characterize the apparent size of the source and decay regions of cometary radicals. Newburn and Spinrad (1984) have presented Haser scale lengths for the parents of $C_2$, $C_3$ and CN in several periodic comets. These were obtained by two-point filter photometry: one point centered on the photometric nucleus and another displaced some known distance from the nucleus (typically 1 to 4 x $10^4$ km). Since Haser's model is basically a three parameter model (the production rate and two scale lengths), Newburn and Spinrad had to assume the values of A'Hearn (1982) for the radical decay length. From two points they could then calculate both a parent scale length and the production rate. Although errors could arise from both this assumption and that of spherical symmetry (i.e., no radiation pressure distortion), a large number of observations may average out some of the random discrepancies.

Figure 4 shows a plot of the CN parent scale length versus heliocentric distance for the combined data sets of Newburn and Spinrad (1984), Combi and Delsemme (1980) and Delsemme and Combi (1983). There is no gross systematic difference between the two data sets. The scale lengths of Newburn and Spinrad were determined from the two-point photometry of smaller short period comets at medium to large heliocentric distances, whereas our data were



MONTE CARLO P-T-M
A - C HASER MODEL
LOG (HELIOCENTRIC DISTANCE) (AU)
LOG (Q-CN) (S**-1)
28
27
26
0.1
1.0
10.0

CN PARENT



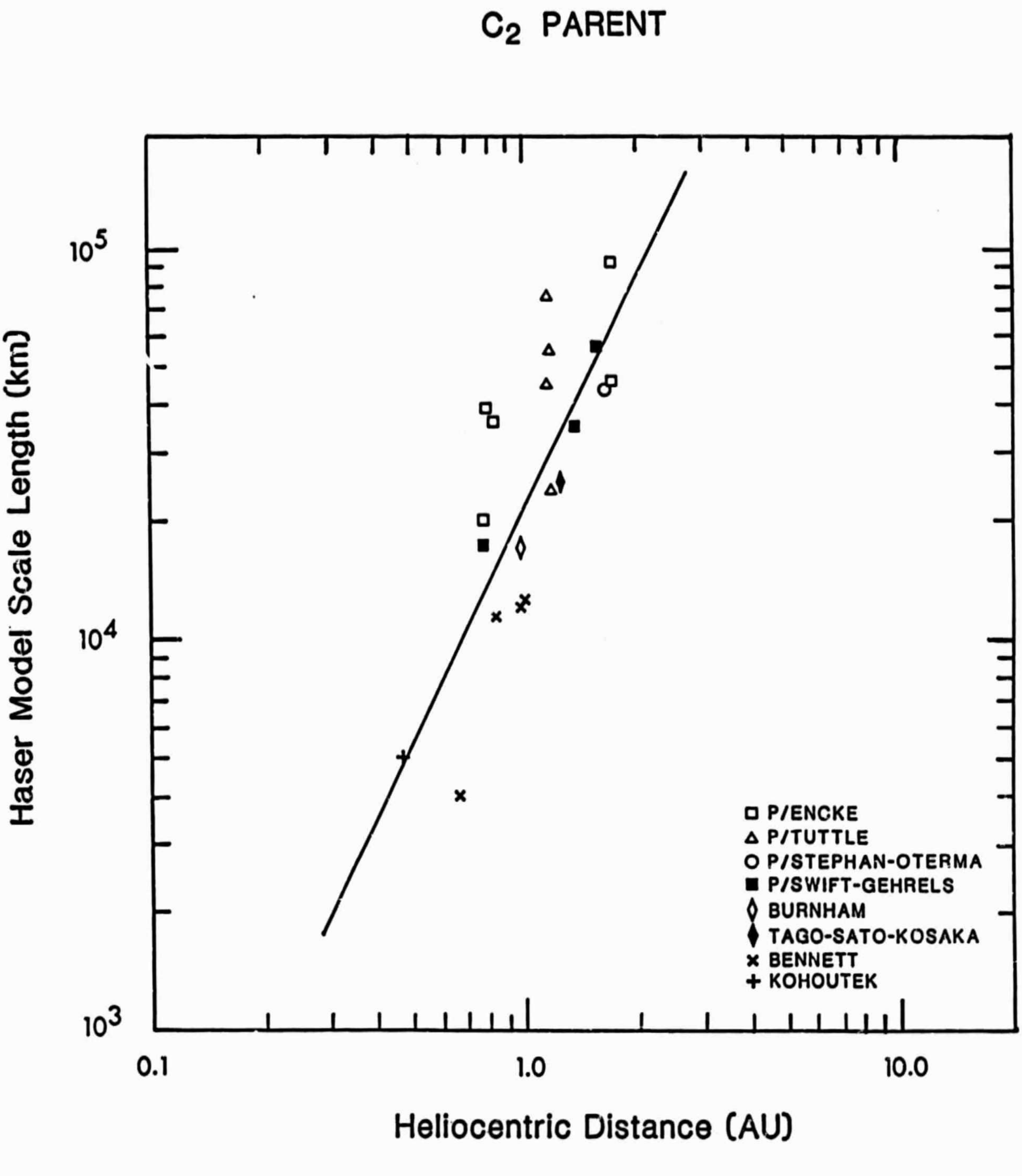
Haser Model Scale Length (km)
$10^5$
$10^4$
$10^3$
0.1
1.0
10.0
Heliocentric Distance (AU)
P/ENCKE
P/TUTTLE
P/STEPHAN-OTERMA
BRADFIELD
P/SWIFT-GEHRELS
BENNETT
KOHOUTEK
WEST

determined from the average of the sunward and antisunward brightness profiles of larger new or very long period comets at small to medium heliocentric distances. Taking all the data together, a power law can be fit which yields the straight line in Figure 4 and which has the form $\lambda_p = 1.6 \times 10^4\ r_H^{1.44}$ for $\lambda_p$ in km and $r_H$ in AU.

The slope for this fit has an uncertainty of about ±0.3 generally excluding both the typically adopted $r_H^1$ or $r_H^2$ laws. An $r_H^{1.5}$ law, on the other hand, would be expected for a photodissociation lifetime ($\tau \propto r_H^2$) and a variable parent velocity ($v \propto r_H^{-0.5}$).

Figure 5 shows the variation of the $C_2$ parent scale length with heliocentric distance for the combined data sets. Unlike the case for CN, though, there does seem to be a systematic difference. The scale lengths of Newburn and Spinrad tend to be both larger and exhibit a flatter slope than do those of Combi and Delsemme (1985). Taken together, a power law in $r_H$ can be fitted to all the data which have the form $\lambda_p = 2.1 \times 10^4\ r_H^{2.0}$. Our data taken alone has the form $\lambda_p = 1.4 \times 10^4\ r_H^{1.8}$, whereas the data of Newburn and Spinrad yield $\lambda_p = 3.8 \times 10^4\ r_H^{0.7}$.

At this point, there could be two reasons for such a difference. First, the $C_2$ spatial distribution in the smaller short period comets may be substantially different from that in the more active new and very long period comets. If $C_2$ were produced primarily by gas phase chemical reactions or an icy grain source as suggested by A'Hearn and Cowan (1980), there should certainly be differences between the two populations of comets. Second, there could be differences between the two model fitting procedures which did not surface in the CN data. The $C_2$ radical experiences nearly twice the acceleration and is likely moving at a lower speed than is CN (Combi and Delsemme 1985). Since the two-point photometry method does not average out the asymmetry, systematic differences could result.



C₂ PARENT
Haser Model Scale Length (km)
$10^5$
$10^4$
$10^3$
0.1
1.0
10.0
Heliocentric Distance (AU)
P/ENCKE
P/TUTTLE
P/STEPHAN-OTERMA
P/SWIFT-GEHRELS
BURNHAM
TAGO-SATO-KOSAKA
BENNETT
KOHOUTEK

## II. Program of Research for the Next Quarter

Research activities in the next quarter will concentrate on (1) development of a multiple collision algorithm for the MCPTM to treat neutral-neutral collisions in the inner coma, and (2) preliminary model runs for the OH distribution.

## References


A'Hearn, M.F. (1982), in Comets, edited by Laurel L. Wilkening, The University of Arizona Press, Tucson, AZ, p. 433.

A'Hearn, M.F. and J.J. Cowan (1980), Moon &. Planets 22, 41.

A'Hearn, M.F., C.H. Thurber and R.L. Millis (1977), A.J. 82, 518.

Combi, M.R. (1980), Ap. J. 241, 830.

Combi, M.R. and A.H. Delsemme (1980a), Ap. J. 237, 633.

Combi, M.R. and A.H. Delsemme (1980b), Ap. J. 237, 641.

Combi, M.R. and A.H. Delsemme (1985), in preparation.

Delsemme, A.H. (1982), in Comets, edited by Laurel L. Wilkening, The University of Arizona Press, Tucson AZ, p.85.

Delsemme, A.H. and M.R. Combi (1983), Ap. J. 271, 888.

Newburn, R.L. and H. Spinrad (1984), A.J. 89, 289.

Schleicher, D.G. and M.F. A'Hearn (1982), Ap. J. 258, 864.

Schleicher, D.G. and M.F. A'Hearn (1984), Bull. AAS 15, 806.

Tatum, T.B. and M.J. Gillespie (1977), Ap. J. 218, 569.

**Figure Captions**

Figure 1. Photodissociation Lifetime of OH as a function of Heliocentric Velocity (Schleicher and A'Hearn 1982).

Figure 2. Excitation Rate for the OH(0-0) Band. The heliocentric velocity dependence is shown for heliocentric distances of 0.25 AU and 1.00 AU (Schleicher and A'Hearn 1984).

Figure 3. CN Production Rate vs. Heliocentric Distance. The CN Production rates for Comet West are shown as computed both with the Haser model scale lengths of A'Hearn and Cowan (1980) [0] and with the Monte Carlo particle trajectory model which includes radiation pressure and a variable parent velocity [+]. Intermediate cases are discussed in the text.

Figure 4. CN Parent Scale Length vs. Heliocentric Distance. The points plotted for Comets P/Encke, P/Tuttle, P/Stephan-Oterma and Bradfield were computed from two-point filter photometry by Newburn and Spinrad (1984). Those for Comets Bennett, Kohoutek and West were computed from entire brightness profiles (Combi and Delsemme 1980b, Delsemme and Combi 1983). The solid line is the best fit power law to the combined data sets.

Figure 5. $C_2$ Parent Scale Length vs. Heliocentric distance. The points plotted for Comets P/Encke, P/Tuttle, P/Stephan-Oterma and P/Swift-Gehrels were computed from two-point filter photometry by Newburn and Spinrad (1984). Those for Comets Burnham, Tago-Sato-Kosaka, Bennett and Kohoutek were computed from entire brightness profiles (Combi and Delsemme 1985). The solid line is the best fit power law to the combined data sets.